RESEARCHES UPON THE GENERAL PHYSIOLOGY OF NERVE AND MUSCLE.

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No. 2.

Resistance offered by Nerve and Muscle to the passage of an Electrical Current. It was shown by the authors in a previous communication made to the Academy, No. 1, that both muscle and nerve are the seats of electro-motive force amounting in the case of muscle to the 0·0696, of nerve to the 0·0237 of a Daniell, capable of deflecting the magnet of a Wiedemann galvanometer as indicated by the scale to an extent of 217 and 21 divisions respectively. Now since the current after passing from the muscle or nerve to and through the galvanometer, in returning to the point from which it started, must pass through the muscle or nerve, it becomes a matter of importance as well as of interest to determine the resistance offered by the latter which must be overcome by the muscle and nerve current as the internal resistance of the battery must be overcome in order that the electrical circuit may be completed. The method made use of by the authors in determining the resistance offered by muscle, nerve etc. to the passage of an electrical current is that known as the Wheatstone bridge method, a brief account of which is indispensable to the proper understanding of the apparatus to be presently described and by which the results to be communicated were obtained. To illustrate the theory of the Wheatstone bridge let us suppose that a current from a Daniell element D enters the wire A B Fig. 1 at A, the wire being graduated into 1000 parts and along which the slider S can be moved; such being the case if the slider be pushed along the wire close up to A, then of the current entering at A, part returns through the galvanometer G and part returns through A S B to the Daniell element whence it came.

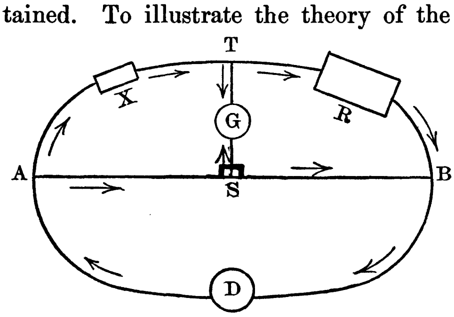

Fig. 1.

Suppose, however, that the slider be pushed from B only as far as S, then the current entering at A will divide into two branch currents passing respectively to S and X. The one branch current on reaching S will subdivide again into two currents one of which will return through S B to the Daniell element the other passing into the galvanometer G and deflecting the needle to the left for example, supposing it to be unopposed by the current which we shall see passes into the galvanometer G in the opposite direction from T. The other branch current on passing through X, the muscle or nerve whose resistance is to be determined, on reaching T will similarly divide into two currents, one of which passing through the resistance box R will return through B to the Daniell element; the other passing into the galvanometer will deflect the needle to the right supposing it to be unopposed by that passing into the galvanometer G from S in the opposite direction. The resistance box just referred to, Fig. 2, is so called on account of its offering a resistance to the passage of an electrical current the amount of resistance offered being determined by the number of plugs out. Let

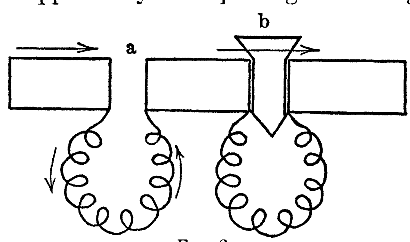

Fig. 2.

us suppose for example, the slider being at B, that we make the resistance box offer a resistance of 100 ohms (1) by taking out the plug numbered 100, Fig. 2 a, the effect of this will be that of the current which would otherwise return through R to the Daniell, part now passes into the galvanometer and deflects the needle to the right. Let now, however, the slider be moved from B to S, that is to exactly the middle of the wire or to its 500th division, it will be observed that the needle of the galvanometer G is deflected back to zero, proving that of the current which, when the slider was at B, returned to the Daniell element, part now passes into the galvanometer G opposite in direction to that passing in the galvanometer from T, but with an equal electro-motive force since the needle of the galvanometer is brought to zero. Let us suppose in order to illustrate graphically the relation of the forces involved in

An ohm is the resistence offered by a copper wire 1 mm. in diameter and 46·25 mm. in length.

the preceding experiment that the vertical line A E Fig. 3 represents the electro-motive force of the current as it enters A Fig. 1 from the Daniell and that the horizontal line A S B Fig. 3 represents the resistance offered by the wire A S B Fig. 1, S representing in Fig. 3 the point where the current passes into the galvanometer from S in Fig. 1, S G in Fig. 3 will then represent the electro-motive force of the current at the point S. It need hardly be added that S G must be shorter than A E since the electro-motive force at S is necessarily less than at A, the electro-motive force diminishing gradually from A to B. Similarily A E Fig. 4 representing the electro-motive force at A Fig 1, let A T B represent the resistance offered by A X R B Fig. 1 to the passage of the current. The line A T B Fig. 4 being shorter than the line A S B, the resistance being greater, the electro-motive force will be diminished more suddenly and the point T where the current from T Fig. 1 passes into the galvanometer will consequently be nearer A, and T G Fig. 4, will then represent the electro-motive force at that point and being equal to the electro-motive force at S Fig. 3 it must be equal to S G. But if S G be equal to T G, which must necessarily be the case since they represent the electro-motive forces through whose equal and opposed effects the galvanometer needle remains at zero, it follows that A T : T B : : A S : S B or what is the same thing that X : R : : A S : S B (1). Substituting in (1) the values of R, A S, S B as experimentally determined and we obtain X : 100 : : 500 : 500 or X = 100 ohms. That is to say that X the nerve or muscle offers a resistance to the passage of an electrical current that is equal to 100 ohms. In deter-

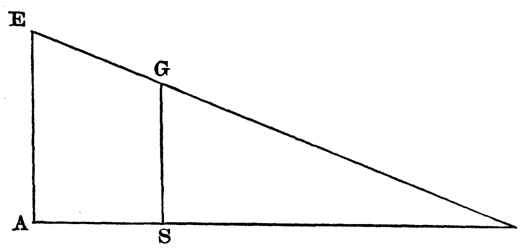

FIG. 3.

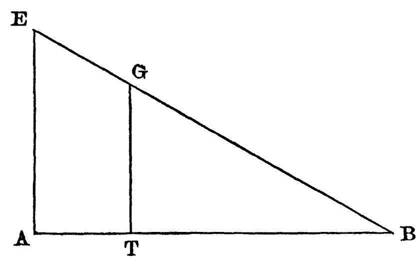

FIG. 4.

mining the resistance offered by muscle and nerve to a current of electricity as in the case of the determination of the electro-motive force of the same, the authors made use however of the round compensator Fig. 5 with Christiani's modification, that is with the addition of the binding screw O, a much more reliable and convenient instrument than the long rheocord. The relations existing between the resistance to be determined or X and that of the resistance box R and the portions of the wire A S S B on either side of the wheel S are, however, precisely the same as in the case of the long rheocord since in both cases the ratio obtains of X : R : : A S : S B as may be at once seen by a comparison of Figs. 5 and 1.

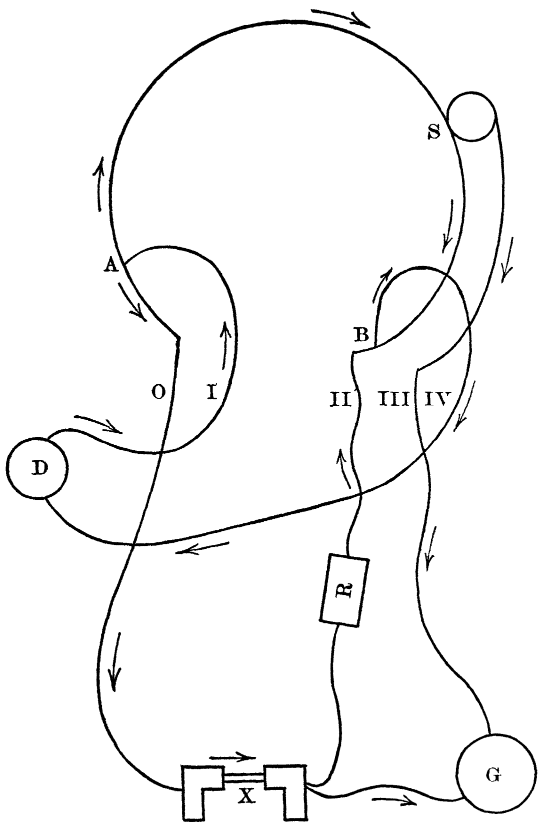

FIG. 5.

In order that the amount of muscular and nervous tissue used in the different experiments should be the same the authors made use of the method employed by Hermann (1) of enclosing the tissue between two plates (in the present instance of ebonite instead of glass) to the four corners of one of which were cemented pegs so that when the other plate rested on the latter a definite space was included. It would have been desirable if practicable that the same amount of nerve had been used as muscle but on account of the scarcity of frogs, the season being winter and the great number of

sciatic nerves that would have been required to have filled up the space, amounting in the case of the muscle to 2 cent. in length and breadth and 1 mm in thickness, a smaller space was made use of in the case of nerve, namely of 2 cent. in length 1 cent. in breadth and 0·5 mm in thickness. It will be observed from the tabulated results given below of the resistance offered by muscle and nerve to the passage of an electrical current, that the resistance varied with the amount of the resistance offered by that of the resistance box. At first sight it might appear that such variations vitiated entirely the result. It must be borne in mind, however, that the polarization due to the passage of the current through the tissue offers a resistance as well as the tissue itself and that this polarization varies with the current, the latter varying in turn according to the resistance box. Such being the case the variations in the resistance offered by the same amount of tissue according as the resistance of the resistance box is modified, may be attributed to the polarization set up in the tissue. It may be mentioned incidentally in this connection that in the absence of a round compensator the resistance of muscle, nerve etc. can be determined, though not so conveniently or accurately, by means of that form of resistance box in which the latter is provided with the Wheatstone bridge arrangement as represented in Fig. 6 and

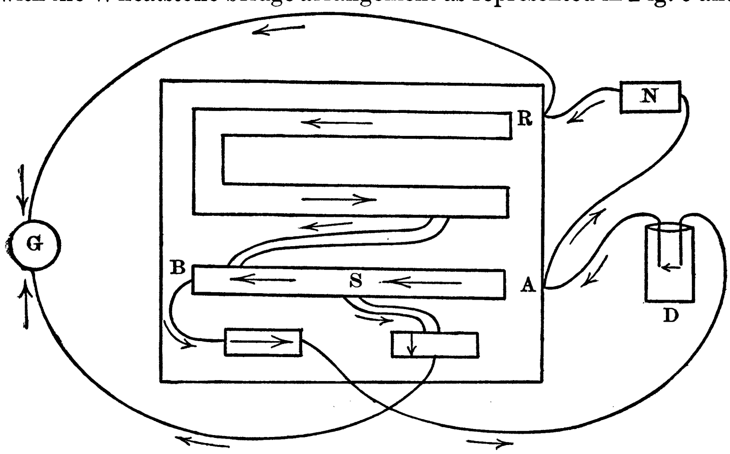

FIG. 6.

which was made use of by the authors with the view of comparing the results as obtained by it and by the compensator. After what has been said as to the general theory of determining resistance it will be

[1] Pflugers Archiv. B and V.

seen that by this particular method the proportion of X : R : : AS : S B obtains as when the round compensator is used, the only difference being that in making at once A S = S B, the value of X is inferred from that of R. In conclusion it may be pointed out that while the resistance offered by the human body to the passage of an electrical current is very great in a state of health, it appears to be diminished in a state of disease, notably in Graves disease, indeed so much so as to constitute an important diagnostic symptom of that condition.

Tabulated results of resistance offered by muscle and nerve of a frog to a current of electricity.

MUSCLE.

Sartorius, length and breadth 2 cent. thickness 1 millim. Resistance of 70 ohms offered by pads including shields in each case deducted from result.

Formula for experiments X : R : : A S : S B, X = Resistance [in ohms.

1st Series		
Longitudinally	X : 2000 : : 478 : 512, X =	1836
Longitudinally	X : 4000 : : 318 : 682, X =	1795
Longitudinally	X : 5000 : : 271 : 729, X =	1788
Mean		1806
Transversely	X : 2000 : : 857 : 143, X =	11916
Transversely	X : 10000 : : 540 : 460, X =	11670
Mean		11793
2nd Series of experiments.		
Longitudinally	X : 2000 : : 515 : 485, X =	2053
Longitudinally	X : 4000 : : 334 : 666, X =	1936
Longitudinally	X : 5000 : : 290 : 710, X =	1972
Mean		1987
Transversely	X : 2000 : : 890 : 110, X =	16111
Transversely	X : 5000 : : 730 : 270, X =	13448
Mean		14779

Ratio of mean longitudinal to transverse resistance as shown by 1st series of experiments 1 to 6·5.

Ratio of longitudinal resistance to that of mercury taken as unity 2006000 to 1, of transverse resistance 13103000 to 1.

NERVE.

Sciatic, length 2 cent. breadth 1 cent. thickness 0·5 mm. Resistance of 47 ohms offered by pads etc. deducted from result.

Formula of experiments X : R : : A S : S B, X = Resistance [in ohms.

1st Series		
Longitudinally	X : 2000 : : 840 : 160, X =	10453
Longitudinally	X : 4000 : : 735 : 265, X =	11047
Longitudinally	X : 5000 : : 690 : 310, X =	11082
Mean		10860
Transversely	X : 2000 : : 880 : 120, X =	14619
Transversely	X : 4000 : : 785 : 215, X =	14557
Transversely	X : 5000 : : 745 : 255, X =	14160
Mean		14445
2nd Series of experiments.		
Longitudinally	X : 2000 : : 845 : 155, X =	10856
Longitudinally	X : 4000 : : 725 : 275, X =	10498
Longitudinally	X : 5000 : : 680 : 320, X =	10578
Mean		10644
Transversely	X : 2000 : : 860 : 140, X =	12251
Transversely	X : 4000 : : 740 : 260, X =	11038
Transversely	X : 5000 : : 685 : 315, X =	11156
Mean		11481

Ratio of mean longitudinal to transverse resistance as shown by 1st series of experiments 1 to 3.

Ratio of longitudinal resistance to that of mercury taken as unity 12066000 to 1 of transverse resistance 32099000 to 1.

It will be observed that the ratio of the longitudinal to the transverse resistance in nerve as well as the ratio of both the longitudinal and transverse resistance in nerve as compared with mercury taken as unity differ from the same ratios obtaining in muscle. It must be borne in mind, however, that this difference is due to some extent at least to the amount of nerve tissue used, being less than that of muscle.